Developing injury prevention strategies through design modification of the Human Machine Interface: A tram driver-cabin case study

Helen Moody\textsuperscript{a}, Alan Burns\textsuperscript{b} Anjum Naweed\textsuperscript{c}

\textsuperscript{a}Injury Prevention and Management, Corporate Health Group; Adelaide, South Australia, AUSTRALIA, \textsuperscript{b}Strategic Connections Group, Melbourne, Victoria, AUSTRALIA, \textsuperscript{c}Appleton Institute, Central Queensland University, Adelaide, South Australia, AUSTRALIA.

In 2014, the Tram Division of the Department of Public Transport and Infrastructure (DPTI) in South Australia identified a high injury rate involving the left arm amongst tram drivers operating the Citadis tram-type in the Adelaide tram fleet in South Australia. An interdisciplinary project team investigated the issue, with a methodology that converged physical ergonomics assessments, human factors investigations and engineering evaluations. Key considerations related to driver-cab interface, including the design of the hand-operated master-controller, vigilance and deadman safety systems, the driver’s seat. Findings revealed issues with the amount of sustained force that was required to operate the master controller and the position of the foot pedal, and how these interfaced with the driver’s seat. The varying anthropometric requirements of the driver cohort intensified the problems due to lack of adjustability in these components. The requirement for drivers to achieve more flexibility in positioning themselves and therefore achieve correct posture when driving was identified. Recommendations for changes were developed following consultation and discussion of findings. This included a mock up of a new driver-cabin configuration, which was constructed after the driver assessments, measurements and structured feedback were undertaken, and redesign of the force requirements for the master controller.

Practitioner Summary: This article presents the injury history and identified injury causal factors in the design of a tram driver cabin, along with the evaluation methods and recommendations. It highlights the collaborative nature of the approach to achieve the outcomes required.

Keywords: Citadis Tram, Cabin Evaluation, Participatory Ergonomics, Musculo-Skeletal Injury, Design Modification

1. Background information

Tram networks the world over can be home to numerous tram types. As old trams come to the end of their service life, new trams are commissioned. More of than not, more than one tram type co-exists with others, presenting driver-cab interface that vary from tram-to-tram and inconsistencies in ergonomics and human factors best practice. As a case in point, the Public transport tram fleet in Adelaide, South Australia consists of 15 Flexity trams and 6 Citadis trams. There are 72 tram drivers who operate this fleet. The 6 Citadis trams were introduced in 2009 and following the implementation of these trams, left shoulder and arm injuries started being reported, directly related to driving this particular variety of tram. In 2014, there were a total of 12 drivers (9%) with left arm injuries, 8 of these drivers had permanent restrictions on driving time for the Citadis tram and 4 drivers had permanent medical restrictions preventing driving of the Citadis tram. The drivers related their injuries to the force required to operate the master controller combined with problems of the seat height and inability to use dead man’s pedal. There were no left arm injuries related to the Flexity tram. These restrictions created significant problems with the driver roster and concerns regarding increasing numbers of injury reports further restricting tram operations.

The tram operations group investigated other organisations that use Citadis trams and did not find any musculoskeletal issues had been reported in international users. However, the Citadis trams used in Melbourne, Australia, had invoked modifications to their master controllers. Various remedial measures were trialled in Adelaide, South Australia, including individual ergonomic assessments of injured workers, various modifications trialled to the armrest for the left arm and provision of an aftermarket foot-rest. Each of the individual ergonomic assessments identified similar problems, which were the pressure required to operate
the master controller with the left arm, combined with the inability to adjust the seat correctly and still support the feet. These assessments also identified that no driver used the dead man’s pedal due to the difficulty of reaching the device, therefore drivers almost exclusively used the dead man’s (vigilance) sensor on the master controller, which was operated by the thumb.

With continuing injury rates the tram operations group made the decision to investigate redesign of the master controller and selected elements of the tram cabin.

2. Method

A multi-disciplinary team consisting of engineers, human factors specialist, ergonomist and employer/driver representatives from the tram organisation was established and led by Strategic Connections Group. A qualitative ethnographic approach to the problem was used to systematically study the people and culture within the tram-driving environment in situ, and involved a representative sample size, simultaneous data collection and analysis, and value upon subjective facts (Thompson, 2013). Within this method, areas of investigation included the assessment of Cabin ergonomics, particularly the operation of the Citadis master controller, the cabin layout and suitability for a range of driver statures, human factors and task loadings under differing driving conditions along with design and engineering options for change.

Initially, the ergonomic factors related to use of the master controller and the driver operator interface were assessed. This included the controller handpiece, vigilance and dead man’s systems, driver’s seat and any other contributing equipment or activity identified in this process. The Engineers collated the recommendations and developed solutions while ensuring that the vigilance control circuit modifications and changes did not create any unwarranted risks. The tram organisation ensured the practicality of the modifications in relation to the operational requirements and provided assistance with installation.

Initial assessment commenced with a daylong consultation session with representatives of the public transport tram division and driver teams. Drivers were included as part of a focus group and the individual drivers that had incurred left arm injuries were also interviewed separately. Each driver described their understanding of the mechanism of their injury and was viewed in their normal driving position. They were asked to contribute ideas for solutions to solve the problems that they had identified. ‘On road’ testing in a Citadis tram was undertaken in a variety of track conditions along with measurements of the force required to operate the master controller. This was then compared in the same manner with a Flexity-tram where no injuries have been reported.

The approach to develop solutions and improvements was participative, and after collating the initial results, a mock up model of console, seat, modified controller, arm-rest and foot-rest was manufactured. Mock-ups have been found to have significant practical value (Hughes, et. al 2013). It was tested with a group of 29 (40%) of the drivers including anthropometric measurements, self-report questionnaire and free form comments. The results of this trial were then translated into changes to the configuration of the footrest, controller and seat adjustments in line with the initial findings. A trial configuration was installed in one Citadis tram for further driver feedback and usability testing. The second round of usability testing involved six drivers of varying statures followed by on-track testing by a number of other drivers over a period of weeks. At each stage of the project there was close co-ordination with the drivers, rolling stock manager and workshop manager.

3. Results

3.1 Injury mechanisms

Injury type included left shoulder bursitis, tendonitis and combined neck/shoulder muscular problems and thoracic outlet syndrome. The common themes arising from driver interviews were that discomfort was arising several factors. These included the length of exposure and the frequency of actions on the master controller with particular problems described on shuttle shifts where the stop/start actions required result in frequent force exertions on the master controller. The force required to continuously operate the master controller was regarded as excessive, particularly holding the controller in the forward position and conversely pulling it back into the braking position which requires minimal force but uses static muscular control to regulate the speed and ensure smooth stopping. Along with issues of the master controller it was noted that the seat position affected arm posture. A variety of issues were identified depending on the individual’s stature - taller people had the seat all the way back creating increased shoulder flexion, elbow
extension and unsupported forearm position. Those with narrow torsos had their shoulder abducted with external shoulder rotation to reach controller. Unsupported forearm increased static loading on the muscles in this position.

3.2 Related issues

None of the drivers that were interviewed used the deadman foot pedal on the Citadis. The reasons given for this were that they were in the ‘wrong position, awkward position, too small, not comfortable, and lifting the foot on the pedal hurt the front of shin. Another reason was for the lack of proprioceptive feedback through foot associated with the pedal being depressed, therefore being unsure if the sensor had activated. Most drivers said that they would use a foot pedal in preference to thumb operation on the master controller if it was more comfortable and easier to use than the current one.

3.3 Flexity and Citadis tram comparison

Driver comments were favourable regarding the driving of the Flexity in comparison to the Citadis. Comments included - more comfortable position to operate the controller; very easy; no spring load; easier because not spring loaded and has cruise control, more responsive; no force required, Joy stick handle more user friendly as compared to T-bar handle of the Citadis, can get better position; can get closer therefore less shoulder abduction; foot pedal easy; foot pedal user friendly; no use of dead man on hand piece. It was noted that with the Flexity tram there was also a different seated position with no pressure required to operate the controller, the shoulder in a neutral position, elbow bent and forearm supported.

3.4 Master controller- Push Force required left hand and arm

A McMeissen Force Gauge was used for push force testing. At the full forward position, which is maximum speed, 2.4kg push force is required using the left arm to apply the force through the hand which grips the T-bar controller. It was estimated that it is used in this position for 20 - 40% of driving time. Maximum time the controller is held in the forward position is 20 mins (on some routes). In the mid forward position 1.9kg force exertion is required. It was estimated that it is used in this position for 60 - 80% of driving time. When braking a pullback action is required on the controller. There are 3 ‘click’ positions for braking. The force required is not significant but motor control is required to gently adjust through these positions to avoid sudden ‘falling’ into the engaged position and creating a jerking action for passengers. See Figure 1.

![Figure 1](image.png)

Figure 1. Representation of controller positions – upright is neutral, forward positions at any graduations up till full speed. Braking positions require a pullback action.

3.5 Postural Issues

A postural assessment was undertaken for various drivers. It was identified that the postural approach to operating the controller was determined by the person’s anthropometric configuration. Those drivers with taller statures sit back from the controller creating increased shoulder flexion. Drivers with narrow torsos have increased shoulder abduction. The forearm pad was at a declined angle and did not facilitate contact at all controller positions. Most drivers did not use the forearm support pad for long periods.
A static hold position was required to operate the master controller in the fully forward position in a posture of shoulder abduction and forward flexion with no forearm support.

3.6 Force assessment with postural and muscle fatigue considerations

The 3D static strength prediction program (3DSSPP) was used to input data related to the force required on the controller and the posture used, in order to attempt to quantify muscle fatigue in a prediction analysis. The indication was that a 5 minute sustained force would be the maximum time that could be maintained comfortably on the controller while exerting a force of 2.4kg.

4. Control Measures

As the main cause for the injuries experienced was established to be the resistive force (return spring) in the Master Controller combined with the postural approach to its use, the recommendations for change concentrated on these factors. Recommendations included the following points:

- Reduce the force required to operate the master controller to enable easier manipulation in the forward position and decrease the sustained force required. It was proposed to remove the return spring that created the resistive force and develop a failsafe vigilance control circuit design to ensure safety features were maintained.
- Consider using a vertical rounded control handle with a thumb sensor located on top of the controller.
- Provide a larger armrest at horizontal inclination to allow for full forearm support with possible extension to the left of the master controller handle.
- Angle of controller to be in line with the hand/elbow angle when the upper arm is resting to the side of the trunk.
- Adjustable height foot pedal for left foot and support for right foot to facilitate deadman pedal operation.
- Investigate modifications to vigilance alarms and air conditioner noise.

5. Useability Testing

A concept design and selection of optimal solutions for the driver cab interior was developed by Strategic Connections Group followed by manufacture of a mock-up to enable designs to be developed and refined. The design options took into account the space limitations of the dab, cab door position, reach distance to other instruments/controls, desk angle and driver’s knee interference points, foot pedal location, foot well space, cost and risk of implementation. A set of 2D and 3D models captured the layout of the cabin (see figure2) and a ply wood model was then generated. No physical changes could be made to the console configuration or the seat.

As a result of the useability testing further changes were made with the decision to proceed with changing the controller grip from horizontal T bar to vertical post with thumb sensor on top, return spring removal changed the force required to 0.3kg which was viewed very positively by the drivers, the foot pedal range of height adjustability was set at a range of between 50 – 140mm, width of the foot rest needed to be wide enough to accommodate the foot stance however this was not possible in the confines of the cabin shape, increase the rearward travel of the seat, larger armrest allowed greater contact of the forearm while undertaking forward or rearward actions on the Master Controller.
Figure 2. Sketches of Citadis Cab layout
6. **Implementation**

Following modifications made as a result of the mock-up testing; a prototype was installed in one Citadis tram. On-track testing commenced in 2015 involving driver feedback, engineering evaluation and safety assessments particularly related to electrical circuitry. Further modifications were made to the foot pedal position at this stage. It was determined that the width of the foot rest was inadequate to accommodate all requirements for foot stance but that it was at the maximum available width and no more changes could be made. It was also noted that the depth of the foot rest was too small to accommodate all foot sizes however it was determined that it was at the maximum size for the available space and only minor further increases to size could be made. It was determined that the foot rest height adjustments met the initial aim of facilitating use of the dead man’s pedal in a user friendly manner. On initial driver feedback the reports were positive regarding height adjustability.

The vertical controller could not be made short enough to accommodate the sensor for the vigilance system and be useable for all hand sizes. The original T bar horizontal controller was re-installed but with the return spring removed.
7. Conclusions

This project was initiated in response to a significant and specific injury occurrence. It involved many personnel from varied professional backgrounds and occupational skills to produce a collaborative solution to the problem. As the project evolved and the findings and recommendations were developed, evaluation of proposed modifications was undertaken leading to the implementation of the final design changes. The ergonomic and human factors input were only one part of the team approach which included the end users.

In all design projects there are unintended consequences and areas that cannot be fully optimised. In this project the width and depth of the foot rest and height of the vertical controller were sub-optimum and other solutions needed to be considered. At the time of writing the useability assessments had not been completed but initial responses indicated that the modifications would meet the aim of the initial project brief in decreasing the risk factors for left arm musculo-skeletal injuries. An evaluation of the long term effectiveness of the changes will be required to determine the ultimate effect of the changes however initial signs have been promising.

References
